Alpha Particle Nonionizing Energy Loss (NIEL) for Device Applications

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ABSTRACT

A method developed for the proton NIEL calculation previously is extended to incident alpha particles in this study: ZBL screened potential for Coulomb interactions and MCNPX "thin target approximation" for nuclear interactions.

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I. INTRODUCTION

The proton induced nonionizing energy loss (NIEL) for representative device materials was computed and reported by the authors in [1], [2] for the energy range from the damage threshold to 1000 MeV. The Ziegler, Biersack, Littmark (ZBL) screened Coulomb potential at lower energies and the relativistic kinematics at higher energies were used to compute the Coulomb contribution to NIEL. For the nuclear interactions, we fully accounted for nuclear elastic and non-elastic interactions by utilizing a high energy charged particle transport code MCNPX [3] and appropriate physics models implemented in the code. The results not only were consistent with those from previous studies, but also paved the way for a very promising method to extend the proton NIEL calculation to many materials or combination of materials which had not been easy to compute before. The method developed has many applications, including ion implantation and space environment effects. Two studies have already been performed using our method to examine proton damage effects on bandgap engineered HgCdTe detectors [4] and on light output variations in gallium nitride light emitting diodes [5]. Their studies demonstrated that the method is very useful and that the results are in good agreement with experimental results. Furthermore, in space applications where the proton energies can be very high, it has been observed that the inclusion of nuclear interaction mechanisms when computing the proton NIEL is important in obtaining the correct NIEL values, especially for high Z target materials.

Alpha particles are also a constituent of the space environment. They can be found in solar energetic particle events as well as in background interplanetary Galactic Cosmic Rays. Also, there is a small amount of alpha particles in the Earth's inner radiation belt [6]. Although the relative abundance of alpha particles in the space environment is small compared to that of protons (e.g., see Fig. 1), damage effects of alpha particles can be significant because alpha particles are about 18 times as damaging as protons at a given energy [8]. While NIELs for protons, electrons, neutrons, etc. have been studied extensively and published in many places [e.g., see [9] and reference therein], the availability of published alpha particle NIEL is limited to a couple of references [8], [10]. Furthermore, only the Coulomb contribution was included in the computations at that time. The alpha particle NIEL that includes the contributions from all relevant physical interactions (Coulomb and nuclear elastic/non-elastic) has never been available.

In this paper we present the alpha particle NIEL by utilizing the same method developed for the proton NIEL [1]: the ZBL screened potential for the Coulomb interaction and the MCNPX "thin target approximation" for the nuclear interaction. We compute the alpha particle NIELs for the same 10 materials studied in [1] – C, Al, Si, P, Ga, Ge, As, In, Cu and Se. Incident alpha particle energies covered are from 100 eV to 4 GeV (= 1 GeV/nucleon).

II. ATOMIC COULOMB INTERACTIONS

Messenger et al. [2] derived an analytical model for calculating NIEL for heavy ions based on the ZBL screened potential in the non-relativistic limit. We used the same method for computing the proton NIELs in the previous study, and applied it again here for the alpha particle incident cases. The effect of using the screened potential becomes appreciable at lower energies, where a reduction of the Coulomb potential because of the electrostatic screening of the nuclear charges by the space charge of the innermost electron shells becomes important. The classical Rutherford potential does not account for this screening effect properly, resulting in overestimation of NIEL at lower energies. This is clearly illustrated in Fig. 2, where the alpha particle NIELs computed by two different Coulomb potential formula are shown for silicon. However, we did not include the relativistic effect this time because its contribution to the total NIEL should be relatively small in the energy range considered in this paper.

III. NUCLEAR INTERACTIONS

A MCNPX "thin target approximation" method developed for computing proton and neutron NIELs from the nuclear interactions [1], [11] was used again in this paper for incident alpha particle cases. Fig. 3 shows the results for silicon, which shows the separate contributions of nuclear elastic and non-elastic interactions. Complete description of the relevant nuclear physics, especially specifics to alpha particle interaction with nucleus, will be included in the final paper.

IV. PRELIMINARY RESULTS

Figs. 4 shows the results obtained for silicon, arsenics, and gallium targets. The results for other materials will be shown in the final paper. The effects of using the ZBL screened Coulomb potential at lower energies and of including nuclear contributions at higher energies are evident.

One of previous studies demonstrated [4] the importance of understanding recoil and damage energy distributions for pixelized detector systems, which are increasingly used for measuring the infrared region of the electromagnetic spectrum. In this regard, we will also present and discuss in the final manuscript the recoil and damage energy distributions in selected target materials when bombarded by alpha particles, especially in the context of differences between alpha particle and proton incident cases.

V. CONCLUSION

A computational method developed for the proton NIEL was successfully extended to the alpha particle NIEL calculations in this study.

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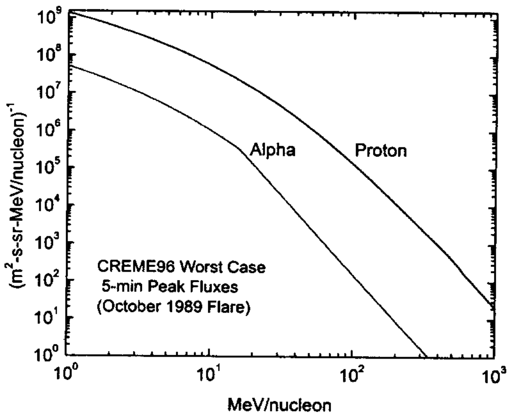

Fig. 1. Worst case 5-min averaged proton and alpha particle differential spectra during the October, 1989 solar energetic particle event from CREME96 [7]. The alpha particle flux is about 5% or less of the proton flux over the entire energy range shown.

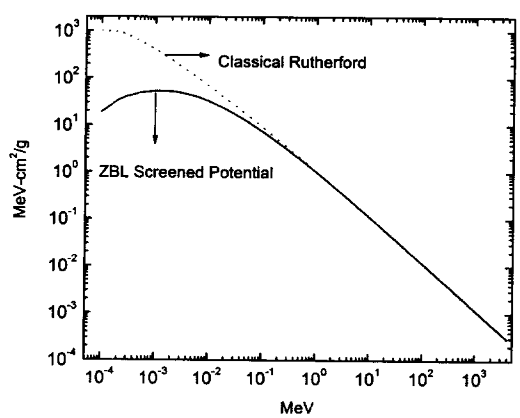

Fig. 2. Alpha particle NIEL for silicon due to the Coulomb scattering, computed using two different formalisms.

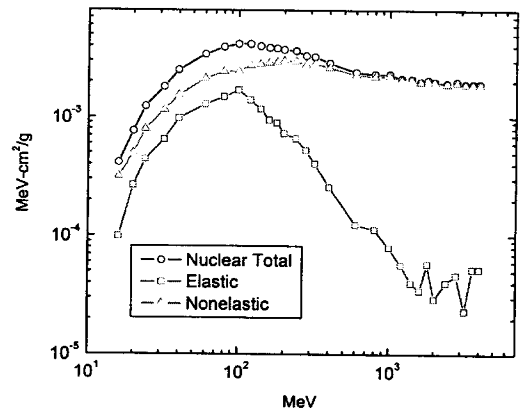

Fig. 3. Alpha particle NIEL for silicon due to the nuclear interactions. The fluctuation of the elastic NIEL at higher energies (> 1 GeV) is due to insufficient number of particles simulated during the MCNPX calculations. However, its contribution is negligible, as shown, and thus no further effort was done to refine the elastic NIEL at these high energies.

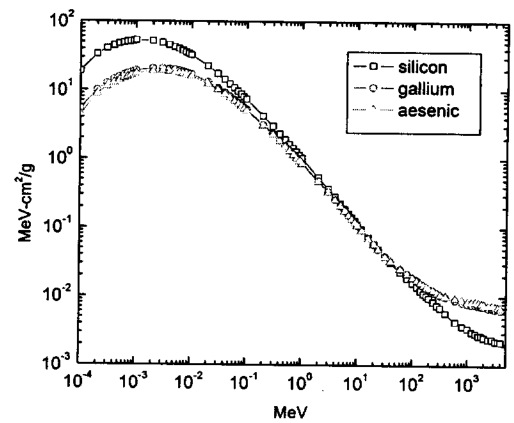

Fig. 4. Alpha particle NIELs for Si, Ga, and As. The results shown include the contribution of Coulomb and nuclear interactions.